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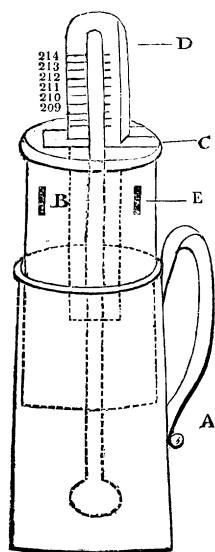
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IX.—*On the Use of Common Thermometers to determine heights.*

By Lieut.-Col. W. H. SYKES, F.R.S.

HAVING been recently applied to by two gentlemen about to travel—the one in Africa and the other in Asia Minor—for a description of the thermometers and apparatus used by myself for some years in India for determining heights by the boiling temperature of water, I have ventured to believe that a brief account of a process which I found to produce results sufficiently near to the truth for most practical purposes, may not be unacceptable to some members of the Society, particularly as I carried on my barometrical observations contemporaneously, and thereby obtained data for fixing the value of certain points on the thermometric scale. To determine heights accurately, good barometers are necessary, which have been carefully compared with a standard barometer; the observations must be taken simultaneously at the upper and lower stations, and the temperature of the mercury and the air, and the hygrometric state of the latter, must be noted. Heights so determined, when tested again in the same or succeeding years, I have rarely found to vary more than 10 or 20 feet in 4000 or 5000. When barometers are used which have not been previously compared with a standard, when the observations are not simultaneous, and when the pressure and temperature at the level of the sea are *assumed*, the results may by accident be near to the truth, but they will usually be from 100 to 300 feet wrong,—at least such is the result of my experience within the tropics. But good barometers are very costly; they are troublesome to carry, are particularly exposed to accident on a journey, and get out of order by the escape of the mercury, which being frequently unobserved, the barometer continues to be used as if it were correct. The late Archdeacon Wollaston, aware of these facts, invented the thermometric barometer to supply the place of the ordinary barometer. This instrument is very sensible, but it is very fragile from the great weight of the bulb compared with the slenderness of the stem; moreover, there are some complex accompaniments, and the instrument is also expensive: in short, I found it not fit for *rough work* out-of-doors, having had three destroyed at the outset of my labours; and the same opinion is expressed by Mr. James Prinsep, of Calcutta, who is well known for the practical application of his scientific knowledge. I had then recourse to common thermometers, and, with certain precautions in their use, found them answer my purpose sufficiently well. A tin shaving-pot was my boiler; dry sticks and pure water were usually to be had, and by

the time my barometers were settled I was ready to take the boiling temperature. The following is a sketch of the apparatus.



A, A common tin-pot, 9 inches high by 2 in diameter.

B, A sliding tube of tin moving up and down in the pot; the head of the tube is closed, but has a slit in it, C, to admit of the thermometer passing through a collar of cork which shuts up the slit where the thermometer is placed.

D, Thermometer, with so much of the scale left only as may be desirable.

E, Holes for the escape of steam.

It will be seen that the chief part of the scale usually attached to the thermometer is removed, only so much of it being left as may be desirable: I however permitted the brass scale of one of my thermometers to remain, and I did not discover that it was the cause of error. Previously to taking the thermometers inland, it is necessary to ascertain their boiling points at the level of the sea; for in many instances the scales are so carelessly applied, that a thermometer may indicate a boiling temperature of  $213^{\circ}$   $214^{\circ}$  or  $215^{\circ}$  at the level of the sea; one of mine stood at  $214.2$  when water boiled. Nevertheless, by making a deduction of  $2^{\circ}$   $2'$  in all observations, the indications rarely differed five-hundredths of a degree from the other thermometer, of which the boiling point was  $212^{\circ}$ : the temperature of the air and the height of the barometer at the time the verification of the thermometers is made must be noted. The following is the manner in which my observations were taken:— from 4 to 5 inches of *pure* water were put into the tin pot; the thermometer was fitted into the aperture in the lid of the sliding-tube by means of a collar of cork; the tin tube was then pushed up or down to admit of the bulb of the thermometer, being about *two inches*, above the bottom of the pot. Violent ebullition was conti-

nued for 10 minutes or a quarter of an hour, and the height of the mercury was repeatedly ascertained during that time, and the temperature of the air was noticed. Similar operations were repeated with a *second* thermometer, for it is never safe to rely upon *one* instrument. Having obtained the boiling points, it remains to determine the value of the indication of diminished pressure when the observations are taken above the level of the sea. The elastic tension of steam at different points on the thermometric scale has been determined by experiment, but not at regular intervals on the scale, nor with similar results, by different persons; tables, therefore,

computed from the formulæ of the various experimenters do not accord; but, in three tables which I have in my possession, the heights computed by them, when compared with heights determined by corresponding barometrical observations, with previously compared barometers, (the only satisfactory way to ascertain heights not taken trigonometrically,) approximate sufficiently near for all practical purposes where great accuracy is not desired. These tables, however, differ slightly from each other.

The table which first came into my hands appeared anonymously in the Madras Gazette for 1824. In 1826 an able friend, Lieut. Robinson, of the Indian Navy, who entered warmly into my views to determine heights by common thermometers, thought he could improve upon the table I was using, and accordingly made a new computation; the third table came under my notice much more recently than the two former. It is computed by Mr. James Prinsep, of Calcutta, Secretary of the Asiatic Society of Bengal, a gentleman distinguished for his scientific research. He published it in the Journal of the Society. To admit of a just estimate being formed of the value of these tables,—of the value of corresponding barometrical observations, made with due precautions, although with different coadjutors and different instruments,—of the value of barometrical observations, with an assumed pressure and temperature, at the level of the sea,—of the value of thermometrical compared with barometrical observations,—out of many hundred heights determined in various ways, I have taken many at random, (the number it appears is eighty-eight,) and I have put them into juxtaposition in a tabular form. In thermometric heights the elements at the level of the sea were a boiling temperature of  $212^{\circ}$  Fahr. and a mean temperature of the air of  $82^{\circ}$ . The *assumed* pressure in heights determined barometrically, without corresponding observations, was 30 inches; mean temperature  $82^{\circ}$ . In looking over the tabulated results I was a good deal surprised to find that in no instance, by whatever method determined, do the barometric differences in height exceed 127 feet, and this only by comparing the highest indications with an assumed pressure with the lowest indications of corresponding observations. It will be seen that the various tables for determining heights thermometrically, with certain exceptions, do not differ very *materially* in their results from each other, nor from corresponding barometric observations; the formulæ on which they are founded may therefore be considered, on the whole, sufficiently accurate for the present state of our knowledge.

Lieut. Robinson's and Mr. Prinsep's tables give close approximations to each other in their results, but they are as much below

the corresponding barometric observations, which I consider the true heights, as the results by the Madras table are above the true heights. Some of them curiously coincide within a foot or two of the heights determined by corresponding barometrical observations, but this coincidence must be the result of mere accident. Taking the mean of all the thermometric observations at a station calculated by the three tables, and the mean of all the corresponding barometric observations at the same place, the utmost difference is 107 feet in less than 600; and the least difference is 8 feet in about 3000; but, as the thermometric heights in which the difference of 107 feet occurs were single observations, made by a gentleman who had newly begun to use his thermometers, they may be looked upon as probably less accurate than subsequent trials would have made them. This is scarcely an unjust inference, as it will be seen that the next greatest difference made by the same gentleman was only 24 feet in 4490. It must be admitted however that this amount of error is just as likely to occur in heights of 100 feet as in those of 10,000. My thermometers were not graduated to less than half-degrees, and long practice enabled me to determine the height of the mercury in the stem to one-twentieth of a degree; but I would recommend thermometers being used in which the degrees are graduated to fifths or tenths of a degree. On the whole, I think the results of six years' experience justify me in saying that common thermometers may be satisfactorily used to supply the place of barometers in measuring heights where great accuracy is not required, and it will be recollected that what is usually looked upon as a difficult and troublesome operation with barometers, will be attainable by any person who carries with him a couple of thermometers, the requisite tin pot, and the tables, and who is master of the simplest rules of arithmetic.

Of the three tables in my possession I have chosen Mr. Prinsep's to submit to the Society, from their perspicuity and the facilities they offer for the conversion of boiling temperatures into heights with very little trouble; but a glance over the figures in my tables of altitudes will show that the tables are susceptible of considerable improvement, for, with two exceptions, all the heights deduced from Mr. Prinsep's and Lieut. Robinson's are much below those determined by simultaneous observations with good barometers; and I join with Mr. Prinsep in expressing a hope that every traveller boiling his thermometers will at the same time, if he possess a barometer, make a record of its indications, and thus render essential service to physics by fixing so many points on the scale of the elastic tension of steam at different temperatures.

Year.	Date.	Names of Places.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
			Jones's Bar. No. 2	Cary's Barometer, the level of the sea.	(Corresponding observations with Capt. Jervis's Gilbert's Bar. and Cary's No. 2.)	Corresponding observations with Dr. Walker's Gilbert's Bar.	Corresponding observations with Capt. Jervis's Gilbert's Bar. and Cary's No. 2.	Corresponding observations with Capt. Jervis's Gilbert's Bar. and Cary's No. 2.	Corresponding observations with Capt. Jervis's Gilbert's Bar. and Cary's No. 2.	Corresponding observations with Capt. Jervis's Gilbert's Bar. and Cary's No. 2.	Heights by boiling therm. 1 by the Madras tables.	Heights by boiling therm. 2 by the Madras tables.	Heights by boiling therm. 1 by the Madras tables.	Heights by boiling therm. 2 by the Madras tables.	Mean of corresponding observations by boiling therm. 1 and 2.	Mean of all the boiling thermometers.
1897	23 May....	{ Highest point, Hill Fort } { of Pirandhur..... }	4588	4599	....	....	....	....	4528	4536	4553	4415	4427	-16	4499	4483
1897	10 May....	Singhur Hill Fort .....	4199	4180	....	....	....	....	4471	4341	4220	3927	3928	-86	4190	4104
1898	15 May....	Temple at Bima Shunkur .....	....	....	....	....	....	....	....	3037	3037	2392	2391	-71	3030	3019
1895	6 March }	Karleh, Cave Temple .....	2493	2652	....	....	....	....	....	{ 9693 2526 }	{ 9646 2536 }	2468	2478	+57	2530	2537
1897	11 May....	{ Highest point of Pirun- } { dhur above Puna .....	2697	2681	....	....	....	....	....	2661	....	2539	2566	-61	2649	2558
1898	23 Feb.... }	{ Pait on the Yail River .....	....	....	{ 42478 42493 }	....	....	....	....	2494	2494	2480	2484	+8	2459	2488
1898	{ 9 Feb.... }	{ Temple in the Hill Fort of }	3872	3931	3845	....	....	....	....	{ 3840 3869 }	{ 3869 3887 }	3824	3788	-46	3892	3846
1829	{ 11 to 17 }	{ Hurchundhur .....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1829	{ Dec.... }	{ Source of Kistna River at }	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1829	{ Dec.... }	{ Mahabuleshwar .....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1898	27 April ...	Pokri .....	....	....	{ 2043 2027 }	....	....	....	....	....	....	....	....	....	....	....
1898	6 April ...	Kullumb, on Goreh River....	....	....	{ 1810 1820 }	....	....	....	....	....	....	....	....	....	....	....
1895	....	Puna, Hay Cottage .....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1897	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1897	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1899	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1898	16 Feb....	Downde, on the Bima River..	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1898	29 Oct. ....	Sasswar, above Puna .....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

\* Boiling temperatures determined by Dr. Walker.

† The heights most relied upon.

TABLE 1.

To find the Barometric Pressure and Elevation corresponding to any observed Temperature of Boiling Water between 214° and 180°.

Boiling Point of Water.	Barometer Modified from Tredgold's Formula.	Logarithmic Differences or Fathoms.	Total Altitude from 30.00 in. or the Level of the Sea.	Value of each Degree in Feet of Altitude.	Proportional Part for One-tenth of a Degree.
°			Feet.	Feet.	Feet.
214	31.19	00.84.3	-1013	-505	..
213	30.59		507	-507	..
212	30.00		0	-509	..
211	29.42	84.9	+509	+509	51
210	28.85	85.2	1021	511	..
209	28.29	85.5	1534	513	..
208	27.73	85.8	2049	515	..
207	27.18	86.2	2566	517	52
206	26.64	86.6	3085	519	..
205	26.11	87.1	3607	522	..
204	25.59	87.5	4131	524	..
203	25.08	87.8	4657	526	..
202	24.58	88.1	5185	528	..
201	24.08	88.5	5716	531	53
200	23.59	88.9	6250	533	..
199	23.11	89.3	6786	536	..
198	22.64	89.7	7324	538	..
197	22.17	90.1	7864	541	54
196	21.71	90.5	8407	543	..
195	21.26	91.0	8953	546	..
194	20.82	91.4	9502	548	..
193	20.39	91.8	10053	551	55
192	19.96	92.2	10606	553	..
191	19.54	92.6	11161	556	..
190	19.13	93.0	11719	558	..
189	18.72	93.4	12280	560	56
188	18.32	93.8	12843	563	..
187	17.93	94.2	13408	565	..
186	17.54	94.8	13977	569	57
185	17.16	95.3	14548	572	..
184	16.79	95.9	15124	575	58
183	16.42	96.4	15702	578	..
182	16.06	96.9	16284	581	..
181	15.70	97.4	16868	584	..
180	15.35	97.9	17455	587	..
					59

The Fourth Column gives the Heights in Feet.

TABLE 2.

Table of Multipliers to correct the Approximate Height for the Temperature of the Air.

Temperature of the Air.	Multiplier.	Temperature of the Air.	Multiplier.	Temperature of the Air.	Multiplier.
°		°		°	
32	1.000	52	1.042	72	1.083
33	1.002	53	1.044	73	1.085
34	1.004	54	1.046	74	1.087
35	1.006	55	1.048	75	1.089
36	1.008	56	1.050	76	1.091
37	1.010	57	1.052	77	1.094
38	1.012	58	1.054	78	1.096
39	1.015	59	1.056	79	1.098
40	1.017	60	1.058	80	1.100
41	1.019	61	1.060	81	1.102
42	1.021	62	1.062	82	1.104
43	1.023	63	1.064	83	1.106
44	1.025	64	1.066	84	1.108
45	1.027	65	1.069	85	1.110
46	1.029	66	1.071	86	1.112
47	1.031	67	1.073	87	1.114
48	1.033	68	1.075	88	1.116
49	1.035	69	1.077	89	1.118
50	1.037	70	1.079	90	1.121
51	1.039	71	1.081	91	1.123

Enter with the mean temperature of the stratum of air traversed, and multiply the approximate height by the number opposite, for the true Altitude.

When the thermometer has been boiled at the foot and at the summit of a mountain, nothing more is necessary than to deduct the number in the column of feet opposite the boiling point below from the same of the boiling point above: this gives an approximate height, to be multiplied by the number opposite the *mean* temperature of the air in Table 2, for the correct altitude.

Boiling point at summit of Hill Fort of Párun-	°	feet.
dhur, near Púna . . . . .	204.2	= 4027
Boiling point at Hay Cottage, Púna . . . . .	208.7	= 1690

Approximate height 2337

Temperature of the air above . . .	75°
Ditto ditto below . . .	83

Mean 79 = Multiplier 1.098

Correct altitude 2.566 feet.

When the boiling point at the upper station alone is observed, and for the lower the level of the sea, or the register of a distinct barometer is taken, then the barometric reading had better be converted into feet, by the usual method of subtracting its logarithm from  $1\cdot47712$  (log. of 30 inches) and multiplying by  $\cdot0006$ , as the differences in the column of "*barometer*" vary more rapidly than those in the "*feet*" column.

<i>Example.</i> —Boiling point at upper station	-	-	185°	=	<sup>Feet.</sup> 14548
Barometer at Calcutta (at 32°) 29 in.			75°		
Logar. diff.	=	$1\cdot47712 - 1\cdot47349$	=	$00363 \times 0006$	= 218
<hr/>					
		Approximate height	-	-	14330
Temperature, upper station,	76°	} 80 = multiplier	1·100		
Ditto lower,	84°				
<hr/>					
Correct altitude	-	-	-	-	15763

Assuming 30·00 inches as the average height of the barometer at the level of the sea (which is however too much), the altitude of the upper station is at once obtained by inspection of Table 1, correcting for temperature of the stratum of air traversed by Table 2.

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[Newman, Optician, 122, Regent Street, has been in the habit of making these instruments; he recommends the use of copper brazed, instead of tin, as more durable; and a free escape for the steam, or the results will be incorrect from the boiling taking place under pressure; a model may be seen at the apartments of the Royal Geographical Society.—Ed.]

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